Section 8
Bayou Verdine - Nature and Extent

This section describes the nature and extent investigation of the Bayou Verdine AOC. Section 8.1 reviews the reaches and energy areas within Bayou Verdine. The historical activities, including industrial development, are located in Section 8.2. An overview of the analytical program is provided in Section 8.3. Presentation of the data from the RI in Section 8.4 includes the results of the PCA as well as the summary statistics of COPCs in Bayou Verdine. Section 8.5 describes the fate and transport of the COPCs in the AOC, and 8.6 presents the conclusions for Bayou Verdine.

8.1 Introduction

Bayou Verdine is approximately 7 km long, located between the cities of Westlake and Mossville, and north-northwest of Lake Charles in Calcasieu Parish, Louisiana (Figure 2-2). Bayou Verdine's headwaters originate in the farmland north of Mossville and flow primarily south-southeast, entering the Calcasieu River on the north end of Coon Island Loop.

8.1.1 Physical Setting

Relief in the area of the bayou ranges from 1 to 5 m above MSL. The bayou and surrounding area are located within the 100-year flood plain of the Calcasieu River Basin (Figure 2-6). Its headwaters are fresh water that mixes with intermediate to saline water of the Calcasieu River to the south. According to the USFWS National Wetland Inventory Map, the upper reaches of Bayou Verdine (from point of origin to I-10) are comprised of a palustrine wetland system that is periodically flooded during storm events and a riverine segment that is permanently flooded.

The upper reaches of the bayou have water depths ranging from 0.1 to 1.0 m. Through the Conoco facility and downstream of I-10, water depths increase to 1.2 to 2.1 m and are not tidally influenced. The lower segment of the bayou is tidally influenced, with up to 3 to 6 inches of daily water level fluctuation (USACE 1976), and has depths of up to 6 m. The bayou has an estimated average rate of flow of approximately 8 cfs in its southern reaches (USACE 1996). Near the confluence of Bayou Verdine and the Coon Island Loop, Bayou Verdine and the shallow groundwater are in direct communication (IT Corporation 1995).

In addition, three ditches drain into Bayou Verdine; they carry surface-runoff spill and permitted discharges from local industries. The Vista West Ditch, which passes through Sasol and Conoco, is located just downstream from Old Trousdale Road and is approximately 1.6 km in length. The Faubacher Ditch, which is slightly over 1.6 km passes through Sasol and Conoco properties east of the Vista West Ditch. The ditch originates in a residential area before passing through Conoco's land treatment area and Sasol's Chemical Plant and discharging into Bayou Verdine at the Conoco refinery downstream of the Vista West Ditch. The KCSRR Ditch runs along the

KCSRR railroad tracks and discharges into Bayou Verdine south of Faubacher Ditch. The ditch is approximately 2.4 km in length (Figure 8-1).

8.1.2 Energy Systems and Reaches

Bayou Verdine is classified exclusively as a bayou energy system and divided into five reaches (Figure 8-1). The reaches were created based on similar conditions divided by recognizable features such as the Old Trousdale Road and the mouth of the bayou. The use of reaches for this investigation is to assist in evaluating areas that have similar physical characteristics (e.g., grain size, TOC or similar inputs [e.g., outfalls]). By describing contamination by reaches, it is expected that samples from within a reach will have similar fate and transport mechanisms although not necessarily the same contaminants. For Bayou Verdine, the reaches are described as follows:

- **Reach 1**: Bayou Verdine from the confluence with the Calcasieu River to I-10, approximately 1,700 m in length.
- **Reach 2**: Bayou Verdine from I-10 to Old Trousdale Road (Rd), approximately 1,050 m in length.
- **Reach 3**: Bayou Verdine from Old Trousdale Rd to New Trousdale Rd, approximately 1,100 m in length.
- **Reach 4**: Bayou Verdine from New Trousdale Rd to Old Spanish Trail Rd, approximately 1,500 m in length.
- **Reach 5**: Bayou Verdine from Old Spanish Trail Road to approximately 1,500 m upstream, approximately 1,500 m in length.

Overall conditions result in net sediment transport from the bayou. Sediments are received from the undeveloped land to the northwest, Concoco, Sasol, and PPG. Sediment is transported through the bayou to the Calcasieu River, entering at Coon Island Loop. Flow in Bayou Verdine is generally sustained by runoff from industrial, agricultural, and rural residential areas and shallow groundwater under gaining stream conditions. The upper portions (Reaches 4 and 5) of the bayou are generally undisturbed in geometry and vegetation. The lower portions of Bayou Verdine (Reaches 1 through 3) have been channelized but are not routinely dredged. Overall, Bayou Verdine is a low-flow system.

At the confluence of Bayou Verdine and Coon Island Loop, the bayou discharges into a swift, deep channel, which is a conduit for brackish to saline water from the ship channel. The engineered confluence is wider than the natural opening and allows for greater tidal influence and storm surge up the bayou.

Development along Bayou Verdine has defined the current nature of the bayou. Industrial discharges (current and historic), accidental releases and stormwater runoff have contributed to organic and inorganic impacts to surface water, sediment, and biota within the bayou.

8.2 Industrial Setting and Historical Contamination

This section depicts the industrial setting along Bayou Verdine, describing the facilities that are currently discharging, or historically discharged, either stormwater or wastewater into the bayou. In addition, previous investigations of Bayou Verdine are discussed to compare whether concentrations of contaminants have increased or decreased over time.

8.2.1 Industrial Setting

The land around Bayou Verdine is characterized by undeveloped land, mixed rural, residential, commercial, and heavy industrial use; however, industrial applications predominate in the southern section (Reaches 1 through 3) of the bayou. Industries that have been permitted to discharge into Bayou Verdine include PPG; Conoco; Lyondell; Sasol; formerly CONDEA Vista (CONDEA); and Tetra Technologies under the NPDES program (Figure 8-2).

Historical/Current Permitted Dischargers in Bayou Verdine
PPG
Conoco
Lyondell
Sasol (formerly CONDEA)
Tetra Technologies

8.2.1.1 PPG

PPG is located along the west side of Bayou Verdine to the south of I-10, (Figure 8-2) and primarily borders Reach 1 of Bayou Verdine. It is a chemical manufacturing facility producing both inorganic and halogenated organic compounds.

The plant was originally constructed in 1940 to manufacture magnesium during World War II and was operated by Mathieson Alkali Works. The facility was re-named PPG Industries in 1968. In 1960, PPG began producing chlorinated organics (EPA 1998a).

PPG Manufactures:
1, 2-DCA (syn. EDC)
Ethyl chloride
Perchloroethene
Trichloroethene
1,1,1-trichloroethane
Hydrogen chloride
Chlorine
Sodium
Hydroxide
Vinyl chloride monomer

PPG (NPDES Permit No. LA0000761) is authorized to discharge process wastewater through several designated outfalls. Only one outfall discharges to Bayou Verdine (outfall 004). PPG 004 receives flow from the North Dock Area. PPG also discharges to Bayou d'Inde (outfall 001) and the Calcasieu River (outfalls 002 and 003). Each of these outfalls was active as of 1996 (Curry et al 1997). The outfalls are monitored for TSS, BOD, pH, TOC, total residual chlorine (TRC), mercury, copper, lead, and several volatile and semivolatile organic compounds (Curry et al 1997). Compliance records available for the period from January 1979 through October 1998 indicate that several permit discharge violations were reported for outfall 004. Significant releases include release of chlorinated hydrocarbons, copper, and mercury. Chronic release of undefined chlorinated hydrocarbons from April 1985 through September 1997 ranged in quantity from 0.1 to

11,950 pounds (lbs) of material above discharge limits. Copper discharge limits were exceeded by 1.5 to 94.5 pounds per day (lbs/day) from January 1989 through October 1990, and mercury spills from November 1987 through January 1990 reportedly discharged through outfall 004 in quantities ranging from 0.7 to 12 lbs. Outfall 004 (Figure 8-2) discharges into Bayou Verdine (Reach 1) approximately 245 m from where the bayou flows into Coon Island Loop. Flow rate for outfall 004 is approximately 25,000 gpm (Curry et al 1997). Exhibit 8-1 summarizes the sources to outfall 004.

PPG also has an outfall (outfall 003) at the North Docks, which is located along the west side of Bayou Verdine, where it discharges into the Calcasieu River at Coon Island Loop. This area is a repository of discharges or spills from the PPG tank farm (EPA 1998a). PPG has exceeded permit levels for chlorinated hydrocarbons on multiple occasions from outfall 003. Spills directly into the Coon Island Loop include vanadium, 1,2-dichloroethane (EDC), crude EDC/trichloroethylene (TCE) blend, and chlorinated hydrocarbons (Table 8-1). Releases in this area may result in contaminant transport into Bayou Verdine by tidal surge or other physical processes. Exhibit 8-1 summarizes the sources to outfall 003. Enforcement histories for the PPG outfalls are provided in Table 7-1.

Exhibit 8-1 Approved Discharges into or Near Bayou Verdine for PPG (Curry et al 1997)

Outfall	Discharge Area	Approved Discharges
003	Calcasieu River at Coon Island Loop	Plant runoff, catch basin effluent, washdown, storage tank overflow, and small volumes of once-through cooling water during periods of heavy rain
004	Bayou Verdine Reach 1	Plant runoff, catch basin effluent, washdown, storage tank overflow, and primary discharge for once-through cooling water from Plant A

The soil and groundwater in the North Dock and adjacent plant area are heavily contaminated from accidental spills and leaking underground transfer pipes (Curry et al 1997). Contamination has been found in all water-bearing units down to the Chicot Aquifer. The upper three units (10, 20, and 30-foot units) have a direct hydrologic connection with Bayou Verdine and are discharging via two contamination plumes (Curry et al 1997). Two significant groundwater plumes that may impact Bayou Verdine are the EDC plume, which extends into the North Dock area, and the perchloroethene and trichloroethene plume that extends into the southern end of the North Dock area. It should be noted that this RI does not address groundwater contamination, as other State and Federal programs are addressing it. However, known contamination is noted because of its potential affect on the sediment and surface water in Bayou Verdine.

8.2.1.2 Conoco

Conoco is a petroleum refinery located primarily on the north and east side of Bayou Verdine to the north of I-10. The facility covers approximately 675 acres, 75 of which are

Conoco Manufactures:
Natural gas liquids
Gasoline
Kerosene
Diesel and fuel oil
Petroleum and calcined coke
Jet fuels
Lube oil feedstock
Flow enhancer

CDM

3282-941-RTZ-RIRTZ-13707

occupied by the refinery process areas. Conoco's facilities border Reaches 2 and 3 and have been in operation since 1942.

The Lake Charles Refinery is Conoco's largest, with a 226,000 barrel-per-day capacity (Conoco 2002). The refinery processes both heavy, high-sulfur crude and low-sulfur crude and produces a full range of fuel products. It also provides the feedstock for Excel Paralube, Conoco's joint venture facility that produces high-quality lubricating base oils, representing approximately 10 percent of U.S. lubricating base oil production. Conoco has recently upgraded the Lake Charles Refinery to process synthetic crude oil from the Petrozuata heavy-oil joint venture in Venezuela.

Conoco (NPDES Permit No. LA0003026) is authorized to discharge into Bayou Verdine through outfalls 001, 002, 004, 006, 007, 008, and 009. Discharge through outfalls 003 and 005 enters the Calcasieu River. Historical discharge exceedances and spills into Bayou Verdine include EDC, crude oil, diesel, hexavalent chromium, and cobalt among others. With the exception of outfalls 001, 002, and 006, discharge is primarily surface water runoff. However, outfalls 001, 002, and 006 receive process wastewater or overflow from waste treatment or storage areas (e.g., outfall 006 receives overflow from the wastewater sedimentation pond). More contaminated effluent streams are likely to emerge from outfalls 001, 002, and 006. Enforcement histories for the Conoco outfalls are provided in Table 8-1. Exhibit 8-2 lists the permitted discharges as of 1991.

Exhibit 8-2 Approved Discharges into Bayou Verdine for Conoco (Curry et al 1997)

Outfall	Discharge Area	Approved Discharges
001 and 002	Reach 2	Treated process wastewater, ballast water, crude tank drawn water, utility water, cooling tower blowdown, sanitary wastewater, and treated runoff from a process area. These are considered the primary outfalls.
004	Reach 2 (via KCSRR Ditch)	Stormwater runoff from the west central plant area.
006	Reach 2	Overflow wastewater from the sedimentation pond. (Requested deletion from permit in 1995 [Curry et al 1997])
007,008, and 009	Reach 2	Treated sanitary wastewater from package units located in remote areas of the facility. (Requested deletion of 009 from permit [Curry et al 1997])
010	Reach 2	Treated sanitary wastewater from package unit.

8.2.1.3 Lyondell

Lyondell Manufactures:
TDI/ toluene diamine(TDA)
ADI (luxate)
Nitric acid
Trichloroisocyanuric acid
Hydrazine
Hexamethylene diisocyanate (HDI)

The plant was constructed in 1934 on approximately 1,200 acres and operated under Mathieson Alkali Works, Inc., Mathieson Chemical Corporation, Olin Mathieson Chemical Corporation, and Olin Corporation (Olin). In 1996, ARCO purchased Olin's toluene diisocyanate (TDI) and aliphatic diisocyanate

(ADI) businesses, which was then bought by Lyondell in 1998.

Outfalls 025 and 026 (Figure 8-2) have been permitted by EPA (EPA Permit No. LA0005347) to discharge stormwater runoff into Bayou Verdine, Reach 1, since 1987 (Curry et al 1997). In 1993, the outfalls were permitted for ammonia, oil and grease (O & G), pH, and TOC and were part of the total permit limit issued for outfalls 016, 017, 019, 020, 022, 025, 026, 027, 032, 033, and 034, which do not discharge into Bayou Verdine. There were no exceedances for outfalls 025 and 026 into Bayou Verdine as of 1998. Exhibit 8-3 lists the Lyondell Bayou Verdine permitted discharges as of 1991. Table 8-2 presents the enforcement history of Lyondell/Olin up to 1998.

Exhibit 8-3 Approved Discharges into Bayou Verdine for Lyondell (Curry et al 1997)

Outfall	Discharge Area	Approved Discharges
025 and 026	Reach 1	Stormwater runoff

8.2.1.4 Sasol

In 2001, Sasol purchased the former CONDEA companies that include the facility in Lake Charles located north of Conoco. The facility began operations as early as 1965 under a division of Conoco. It was purchased by Vista Chemical Company in 1984 and then by CONDEA in 1991.

CONDEA had two outfalls permitted under NPDES Permit No. LA0003336. Both outfalls discharge into Reach 2 of Bayou Verdine (Figure 8-2; Curry et al 1997). Outfalls 001 and 001B received flow from the Alcohol Unit, East Lake Charles Chemical Plant Sanitary Sewers, Ethoxylate Unit, Normal Paraffin Unit, stormwater, Ethylene Unit, Steam Plant, Linear Alkyl Benzene Plant, Vinyl Chloride Monomer Plant, and blowdown. Exhibit 8-4 summarizes sources to outfalls 001 and 001B.

Exhibit 8-4 Approved Discharges into Bayou Verdine for Sasol (formerly CONDEA, Curry et al 1997)

Outfall	Discharges To	Approved Discharges
001 and 001B	Reach 2 (via Vista West Ditch)	Treated wastewater and process water, once through cooling water, blowdown, washdown, caustic, acid wash, and contaminated stormwater

Outfall 001 is monitored for TSS, BOD, TOC, ammonia, benzene, toluene, 1,2-dichloroethane, chloroform, methylene chloride, sodium hydroxide, total chromium, total zinc, and temperature and has a flow of approximately 1,650 gpm (Curry et al 1997). Outfall 001B, via the Vista West Ditch to Bayou Verdine in Reach 2, was designated as the emergency outfall for all of the above. Vista also listed 10 stormwater runoff outfalls but indicated that none of them met the definition of an outfall for which a permit is required. Table 8-3 presents the enforcement history for CONDEA up to 1998.

8.2.1.5 Tetra Technologies

Tetra Manufactures:
Liquid and dry calcium chloride

Tetra Technologies, Inc. (Tetra) purchased the facility in 1989 from Texas United Chemical Corporation, which is located on the west side of Bayou Verdine to the south of I-10 and encompasses 16 acres. The Liquid Calcium Chloride Plant is located in this area. Secondary containment structures are provided for the acid storage tanks, reactors, and loading/unloading areas at the facility. Stormwater collected from these areas is treated prior to discharge through outfall 001 into Reach 1 of Bayou Verdine (Figure 8-2). The remaining stormwater from the area (comprised of offices, dry plant, parking and warehousing) is directed to a common discharge on the east side of the property and on to Bayou Verdine (Reach 1). In addition, treated sanitary wastewater is discharged through outfall 001, combined with the stormwater described above. Table 8-4 presents the enforcement history of Tetra up to 1998. Exhibit 8-5 summarizes sources to outfall 001.

Exhibit 8-5 Approved Discharges into Bayou Verdine for Tetra (LDEQ 1997)

Outfall	Discharge Area	Approved Discharges
001	Reach 1	Treated sanitary wastewater and stormwater

8.2.2 Historical Contamination

Three previous studies were identified in the CEEAG database that collected samples within the Bayou Verdine AOC. These studies include:

- Toxics Study of the Lower Calcasieu River, Prepared by Research Triangle Institute for the U.S. Environmental Protection Agency - Region VI, Louisiana Department of Environmental Quality and U.S. Geological Survey, March 1990**.** (Conducted in 1988-89, see Appendix A)
- Site Inspection for Bayou Verdine, Prepared by PRC Environmental Management, Inc., for U.S. Environmental Protection Agency - Region VI, May 1994. (Conducted in 1993, see Appendix A)
- Results of Preliminary Sediment and Surface Water Sampling and Analysis in Bayou Verdine and Coon Island Loop of the Calcasieu River, Prepared by McLaren/Hart Environmental Engineering - ChemRisk Division for PPG Industries, Inc., 1994. (Conducted in 1993-94, see Appendix A)

Historical contamination of COPCs identified in this RI/FS is discussed in this section. Samples used in this summary were samples collected within the Bayou Verdine AOC boundaries established for the Calcasieu Estuary RI/FS. Samples located outside this boundary were not used for historical comparison.

8.2.2.1 Volatile Organic Compounds

Within the Bayou Verdine AOC, 1,2-dichloroethane (1,2-DCA, syn. EDC) was detected in the 1988-89 EPA toxics study, the 1993 EPA study and the 1993-94 PPG study (Tables 8-5 through 8-7). In the 1988-89 toxics study, EDC was detected at only one location with a result of 4 µg/Kg. The location was approximately 2,265 m upstream from the confluence of Bayou Verdine and Calcasieu River (approximately 260 m upstream of Faubacher Ditch).

In the 1993 EPA study, EDC was detected twice, below the Old Trousdale Road (Reaches 1 and 2) and once in Reach 4. Values ranged from 14 to 32 µg/Kg, with the highest detection in Reach 2, approximately 1,900 m from the mouth of Bayou Verdine and just below the KCSRR Ditch.

The 1993-94 PPG study collected samples below I-10 in Reach 1. EDC values ranged from 5.95 to 5,000 µg/Kg, with the highest detection approximately 1,365 m from the mouth of Bayou Verdine.

Overall, EDC was detected in minor amounts (5,000 µg/Kg or less). Higher concentrations were primarily below I-10 although minor concentrations of EDC were also noted below the Vista West Ditch and the KCSRR West Ditch.

8.2.2.2 Semivolatile Organic Compounds

8.2.2.2.1 Bis(2-ethylhexyl)phthalate

Bis(2-ethylhexyl)phthalate (BEHP) was detected in the 1988-89 EPA toxics study, the 1993 EPA study, and the 1993-94 PPG study (Tables 8-5 through 8-7). B2EHP was detected at only one location in Bayou Verdine during the 1988-89 EPA toxics study. A sample had a result of 33,000 µg/Kg and was approximately 2,265 m upstream from the confluence of Bayou Verdine and Calcasieu River (approximately 260 m upstream of Faubacher Ditch).

During the 1993 EPA study, BEHP was detected in Reaches 1, 2, and 4, with the highest concentrations in Reaches 1 and 2. Values ranged from 41 to 19,000 µg/Kg. Results of 19,000 and 18,000 µg/Kg were located just downstream of Faubacher Ditch and Vista West Ditch, respectively. A result of 12,000 µg/Kg was detected 280 m upstream from the confluence of Bayou Verdine and Coon Island Loop just upstream of PPG outfall 004.

Overall, BEHP was detected in the highest concentration in Reach 2 midway between Vista West Ditch and Faubacher Ditch down to an area past Faubacher Ditch. A second impacted area was just upstream of the PPG outfall 004 in Reach 1.

8.2.2.2.2 Hexachlorobenzene

Hexachlorobenzene (HCB) was measured in the 1993-94 PPG study, downstream of I-10 (Tables 8-5 through 8-7). The highest concentration of HCB (45,205 µg/Kg) was located at the confluence of Bayou Verdine and the Coon Island Loop near the PPG docks. Values varied throughout the rest of Reach 1, ranging from 393 to 26,316 µg/Kg. Overall, the most impacted area was near the PPG North Dock area.

8.2.2.3 Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) were measured in the 1993 EPA study and the 1993-94 PPG study (Tables 8-5 through 8-7). Total PAHs (the summation of 18 PAH compounds) were detected primarily south of the Vista West Ditch in Reaches 1 and 2, with one detection in Reach 4 (3,030 µg/Kg). In the 1993 EPA study, the highest detection (1,468,000 µg/Kg) was located downstream of Faubacher Ditch. Values ranged from 3,107 µg/Kg in Reach 1 to 1,468,000 µg/Kg in Reach 2.

In the 1993-94 PPG study, values ranged from 1,390 to 666,575 µg/Kg, with the highest detected at the confluence of Bayou Verdine and Coon Island Loop. Values near 100,000 µg/Kg were noted approximately 1,000 to 1,500 m from the mouth of Bayou Verdine, increasing downstream.

Overall, historic data indicates that total PAHs have been most highly concentrated in Reach 2 between the Vista West Ditch and I-10. Consistently high to moderate values have been noted throughout Reach 1.

8.2.2.4 Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) were detected at various locations in Reaches 1, 2, and 4 in the 1993 EPA study and the 1993-94 PPG study (Tables 8-5 through 8-7). Total PCB concentrations ranged from 46 to 110 µg/Kg in the 1993 EPA study, with the highest detection in Reach 2, downstream of the KCSRR Ditch. In the 1993-94 PPG study, values ranged from 80 to 465 µg/Kg, with two values exceeding 400 µg/Kg from 265 to 427 m upstream of the mouth of Bayou Verdine.

Overall, historic PCB data indicates that two PCB areas have been noted, downstream of the KCSRR Ditch and at the mouth of Bayou Verdine. Concentrations were low to moderate and extent was limited.

8.2.2.5 Metals

Several COPC metals were detected in the 1988-89 EPA toxics study, 1993 EPA study, and the 1993-94 PPG study. Of these studies, only arsenic was analyzed in the 1993 EPA study and the 1993-94 PPG study; and only chromium in the 1988-89 EPA toxics study.

8.2.2.5.1 Arsenic

Arsenic was detected in both the 1993 EPA study and the 1993-94 PPG study, with ranges of values of 1.6 to 6 mg/Kg and 1.78 to 10 mg/Kg, respectively (Tables 8-5 through 8-7). In the 1993 EPA study, the highest result was located in Reach 1 just south of I-10. However, a concentration of 5.5 mg/Kg was detected downstream of Vista West Ditch and in Reach 4 near Old Spanish Trail Road, indicating the variability of arsenic.

The highest detection in the 1993-94 PPG study was located approximately 1,300 m upstream from the confluence of Bayou Verdine and the Coon Island Loop. Values are variable from I-10 to approximately 600 m upstream of the mouth of Bayou Verdine. At 600 m, the values become consistent all the way downstream to the mouth of the bayou.

Overall, the arsenic concentrations are low to moderate, with the highest result measured at I-10 in Reach 1; consistent measurements were noted in the lower 600 m of Reach 1, as well.

8.2.2.5.2 Barium

Barium was measured in all three studies, with the highest detected values in the 1993-94 PPG study (Tables 8-5 through 8-7). In the 1988-89 EPA toxics study, values ranged from 74 to 226 mg/Kg, with the highest detections south of I-10 in Reach 1.

In the 1993 EPA study, barium was detected in Reaches 1, 2, and 4, with the highest detection located just south of Old Spanish Trail Road in Reach 4, with a result of 358 mg/Kg. Samples ranged from 46.7 to 358 mg/Kg. Values decrease within Reach 4 and then increase below the Vista West Ditch. Downstream of I-10 in Reach 1, barium values decrease again until the highest detection at the mouth of Bayou Verdine.

Barium results vary in the 1993-94 PPG study from 31 to 580 mg/Kg. The highest result was located approximately 1,300 m upstream of the mouth of Bayou Verdine.

Overall, barium was detected across the bayou; however, the highest detections were seen in Reach 1 downstream of I-10. A second trend is noted downstream of the Vista West Ditch where concentrations were noted as rising in the area downstream of the ditch.

8.2.2.5.3 Chromium

Chromium was only measured during the 1988-89 EPA toxics study (Tables 8-5 through 8-7). Chromium ranged from 15 mg/Kg in Reach 3 to 217 mg/Kg in Reach 2 between the Vista West Ditch and Faubacher Ditch. Chromium values decreased to less than 100 mg/Kg downstream of I-10 in Reach 1.

Overall, chromium was highest in the Reach 2 area between the Vista West Ditch and the Faubacher Ditch.

8.2.2.5.4 Copper

Copper was measured in all three studies, with the highest measured values being from the 1993-94 PPG study downstream of I-10 in Reach 1 (Tables 8-5 through 8-7). In the 1988-89 EPA toxics study, copper ranged from 7 to 58 mg/Kg, with the lowest detection in Reach 3 and the highest in Reach 2 just south of Vista West Ditch. Copper values decrease downstream of I-10 in Reach 1.

In the 1993 EPA study, values ranged from 8.9 to 112 mg/Kg, with the highest detections in Reach 2 south of the Vista West Ditch and downstream of the KCSRR Ditch. Values decrease downstream of I-10 in Reach 1.

Copper results in the 1994 PPG study ranged from 3.29 to 150 mg/Kg, with the highest detection located approximately 966 m upstream from the mouth of Bayou Verdine.

Historically, the occurrence of copper has been downstream of the Vista West Ditch and in upper Reach 1. However, the locations sampled limit interpretation as the entire bayou was not sampled in all studies.

8.2.2.5.5 Lead

Lead was measured in all three studies as shown in Tables 8-5 through 8-7. Lead values ranged from 12 to 129 mg/Kg in the 1988-89 EPA toxics study, with the highest detections located downstream of I-10 in Reach 1.

In the 1993 EPA study, values ranged from 11 to 41.8 mg/Kg and tend to increase moving upstream, with the highest detection located in Reach 1 at approximately 1,000 m upstream of Coon Island Loop. Within Reach 2, concentrations are higher downstream of Vista West Ditch and the KCSRR Ditch.

Values ranged from 7.62 to 217 mg/Kg in the 1993-94 PPG study, with the highest and lowest values located approximately 996 to 1,000 m upstream of the mouth of Bayou Verdine.

Historically, lead has been detected downstream of the Vista West Ditch and approximately 900 m upstream of the mouth of Bayou Verdine.

8.2.2.5.6 Mercury

Mercury was measured in all three studies (Tables 8-5 through 8-7). The 1988-89 EPA toxics study had only two measurements for mercury in Bayou Verdine, each located in Reach 1. Values ranged from 0.1 to 0.2 mg/Kg.

Mercury results in the 1993 EPA study ranged from 0.06 to 0.62 mg/Kg, with values below 0.1 mg/Kg in Reach 4 and increasing to above 0.1 mg/Kg near I-10 in Reach 2. The highest concentration was located downstream of the KCSRR Ditch.

In the 1993-94 PPG study, mercury results ranged from 0.12 to 0.97 mg/Kg, with the highest detection located approximately 1,000 m upstream of the mouth of Bayou Verdine. Values steadily increased from I-10 to the maximum value.

Overall, the highest concentrations were noted near the mouth of Bayou Verdine in Reach 1.

8.2.2.5.7 Nickel

Nickel was measured in all three studies, with the highest value measured in Reach 1 during the 1993-94 PPG study (Tables 8-5 through 8-7). In the 1988-89 EPA toxics study, nickel increased from 15 mg/Kg in Reach 1 to 42 mg/Kg in Reach 2 between Faubacher Ditch and Vista West Ditch.

Results from the 1993 EPA study showed that nickel values increased from Reach 4 to downstream of the Vista West Ditch, and an area just downstream of the Faubacher Ditch. Values ranged from 9.9 to 60.8 mg/Kg.

Nickel values ranged from 4.11 to 68.42 mg/Kg in the 1993-94 PPG study, with values decreasing from a high at approximately 1,000 m upstream of the mouth of Bayou Verdine to the confluence at Coon Island Loop. Values from I-10 to this maximum (1,000 m point) were notably more variable.

Overall, nickel values were highest in the mid portion of Reach 1 (1,000 m upstream of the mouth of Bayou Verdine). Areas with elevated detections were noted downstream of the Vista West Ditch in 1988 and 1993.

8.2.2.5.8 Zinc

Historical zinc concentrations are depicted in Tables 8-5 through 8-7. In the 1988-89 EPA toxics study, zinc concentrations ranged from 369 to 1,234 mg/Kg, with values highest near Vista West Ditch and decreasing downstream toward Faubacher Ditch (Tables 8-5 through 8-7).

Zinc concentrations in the 1993 EPA study ranged from 32.7 to 2,830 mg/Kg. Concentrations are lowest in Reach 4, peaking at a point at the mouth of the Vista West Ditch, decreasing slightly until a point at the KCSRR Ditch confluence, decreasing downstream again toward the mouth of Bayou Verdine. In the 1993-94 PPG study, zinc concentrations ranged from 13.29 to 2,806 mg/Kg, with the highest detection located approximately 1,300 m upstream of the mouth of Bayou Verdine.

Overall, zinc concentrations were highest downstream of the Vista West Ditch and the KCSRR Ditch. A third concentrated area is located approximately 1,300 m upstream of the mouth of Bayou Verdine.

8.3 RI Data Analysis and Interpretation Overview

The following discussions focus on data collected during Phase I and Phase II of the RI. Comparison to historical data trends is discussed in Section 8.6. The analytical program and the results of the data validation and interpretation are presented in Sections 4.6.1 and 4.8. Section 8.3.1 provides a summary of the parameters collected and analyzed. An overview of the data interpretation presented in Section 8.3.2 will describe the objectives of the principal component analysis (PCA), which will be used through the remainder of this section to describe the nature and extent of the contamination as well as the fate and transport of COPCs.

8.3.1 Analytical Program

Samples from Phase I and Phase II were collected within the Bayou Verdine area of concern, which is from where it flows into Coon Island Loop to approximately 7 km upstream. Determination of the nature and extent of contamination in Bayou Verdine was a combined effort by the EPA and Conoco. Conoco collected and analyzed samples from approximately 300 m upstream of the mouth of the bayou to where Bayou Verdine crosses Spanish Trail Road. EPA collected and analyzed samples throughout the remainder of the bayou, but in limited quantity.

The RI for Bayou Verdine included collecting and analyzing sediment, surface water, and porewater samples (Figures 4-2 and 4-8) for a combination of compounds in accordance with EPA SW-846, EPA CLP, and ASTM standard methods. The compounds of interest included VOCs, SVOCs, pesticides, herbicides, PCBs, PCB congeners, dioxin/furans, metals (filtered and non-filtered for surface water), and TPHs. Surface sediment samples were collected from the 0 to 15 cm depth interval in Phase I and from 0 to 10 cm depth interval in Phase II. Multi-depth samples were only collected in Phase I at the intervals: 0 to 15, 15 to 30, and 30 to 45 cm intervals. Surface water samples were collected at mid-depth of the water column in the middle of the bayou. Porewater samples were collected with sediment samples and extracted at the laboratory.

Sample Locations in Bayou Verdine For Chemistry Only (Phases I and II)

- 73 Surface sediment
- 7 Multi-depth sediment
- 12 Surface water
- 2 Porewater

In addition to the chemical parameters discussed above, selected samples were analyzed for chemical/physical properties, which may have included grain size analysis, TOC for sediment only, DOC for porewater only, and pH. Field parameters for sediment were limited to penetrometer measurements and VOC screening. Ancillary properties for surface water samples included alkalinity, ammonia, hardness, and TKN. Field parameters for surface water included temperature, pH, DO, ORP, conductivity, and salinity.

8.3.2 Data Interpretation Overview

Data were interpreted by use of statistical tests such as Wilcoxon Rank Sum (WRS) and the PCA to determine primary COPCs and their fate and transport in the estuary. In this section, an overview of the WRS test is provided in Section 8.3.2.1 to describe how it was used in the data interpretation. In Section 8.3.2.2, a brief overview of the PCA is provided explaining the objectives of this analysis. The development of energy system specific COPCs is described in Section 8.3.2.3 and the general fate and transport mechanisms that will explain the extent of contamination of these COPCs in each of the energy systems is provided in Section 8.3.2.4 through 8.3.2.7.

8.3.2.1 WRS Test

This section describes the results of the WRS test to determine if there is a statistically significant difference between the energy area in Bayou Verdine and reference area conditions. COPCs that were not detected in the reference area were not compared using the WRS test; however, these non-detected COPCs are retained for evaluation. Use of the WRS Test is discussed in Section 4.8.2.3. Results are presented in Table 8-8.

The WRS test compares the probabilities (p-values) with a critical value (alpha) in order to determine whether there is a statistically discernable difference in the median concentrations between the two groups tested (energy area in the AOC versus the reference area). For purposes of interpreting the p-values, two levels of significance were established and presented in Exhibit 8-6.

Exhibit 8-6 Levels of Significance

Level of Significance	Interpretation of Difference
p-value < alpha	Medians may be different
Adjusted p-value < alpha	Medians are different

For the first level of significance (medians may be different), the p-values were compared directly with an alpha value of 0.05 or 95 percent upper confidence limit (UCL) of the median of the COPCs. For the second level of significance (medians are different), an adjusted p-value was calculated using the Bonferroni adjustment method:

adjusted p-value = n(p-value),

where, n is the number of comparison tests conducted.

The test does not indicate whether higher concentrations were observed in the energy area or the reference area, only that there was significant statistical difference between the two areas. To determine which area had higher concentrations, box plots comparing the two systems were examined and are presented in Appendix E.

8.3.2.2 PCA

As discussed in Section 4, PCA was used to accomplish the following objectives:

- Objective 1: Study the correlations of multivariate data sets by grouping variables (analytical constituents or parameters) in principal components (also known as factors or groups). Variables within each factor are more highly correlated with each other than with variables in other factors.

- Objective 2: Summarize many variables by a few factors or groups. Essentially, this is a data reduction technique whereby several original variables may be represented by one or a few "indicator" variables or by the factor itself.

- Objective 3: Interpret each factor according to the "meaning" of the variables. Such interpretation may provide useful information regarding geochemical fate and transport.

Sediment composition is heterogeneous, which means that chemicals found in sediment will vary from one location to the next. The PCA groups the measured parameters into factors, which are parameters that tend to correlate with one another. By identifying parameters that correlate, sediment conditions can be better understood and explain why one location varies from another. Understanding the variability in the surface sediment, conclusions can be made in regard to sources and the fate and transport of contaminants.

Factors from the PCA will be discussed in Section 8.5.2 if one or more COPCs are grouped within that factor.

8.3.2.3 COPC Selection

The COPC list provided in Table 4-2 presents all of the COPCs in the Calcasieu Estuary, however, not all of these COPCs are present in each AOC or energy system. To limit discussion, energy system specific COPCs for each AOC were determined. COPCs that may not be present in a specific energy system, were not risk drivers, or were not statistically significant different than reference area conditions are not discussed.

The HHRA and BERA state which COPCs are the primary risk drivers for each AOC. An energy system specific COPC was determined if the following two conditions exist:

- The COPC was identified as a risk driver in the HHRA or the BERA
- The concentration of the COPC was determined to be statistically significant different and at a greater concentration from reference area conditions

If either of these criteria failed, the COPC was determined not to be a COPC for a particular energy system. In some cases, there was insufficient data to compare a COPC with reference area conditions (i.e., low Frequency of Detectss in a particular energy system). In these instances, the ranges of concentrations of a particular energy system are compared to reference area conditions by examining mean and median values by the use of box plots (Appendix E). If the range is comparable then they are not discussed in the following subsections. Additional information regarding these COPCs is presented in the HHRA or the BERA.

8.3.2.4 Fate and Transport Mechanisms

The major mechanisms that tend to guide chemical fate and transport in estuarine systems are:

- Adsorption
- Precipitation/Co-precipitation
- Salting out
- Complexation

- Biotransformation
- Hydrolysis
- Photolysis

Contaminant occurrence and extent in the Bayou Verdine AOC is dependent upon physical conditions, the contaminants, their concentrations and the dominant processes given these conditions. Details on these fate and transport processes are provided in Section 5.0. Sections 8.4 and 8.5 will discuss the general physical and chemical parameters, the extent of contamination, and the processes controlling COPC behavior in Bayou Verdine.

8.4 General Physical and Chemical Parameters for the Bayou Verdine AOC

This section presents the results of the sediment and surface water characteristics of the bayou energy system in Bayou Verdine.

8.4.1 Sediment Characteristics

8.4.1.1 Particle Size

Particle size analysis was conducted on all 10 SQT samples in Phase II (Figure 8-3). Clay content decreases upstream from the mouth of Bayou Verdine to Reach 3 and then increases in Reach 5. Sand increases within the bayou from the mouth to Reach 2, decreasing upstream. Reach 3 exhibits more silt particles than clay or sand, reaching a maximum in Bayou Verdine in Reach 5. Exhibit 8-7 summarizes the average particle size in each of the reaches, with the exception of Reach 4 where particle size analysis was not performed.

Exhibit 8-7 Mean[1] (Standard Deviation) of Particle Size Analysis

Reach of Bayou Verdine	Percent Clay	Percent Silt	Percent Sand
Reach 1	34.27 (9.92)	26.26 (4.89)	39.47 (13.12)
Reach 2	33.92 (2.93)	18.70 (3.82)	47.38 (0.91)
Reach 3	26.95 (-)	37.29 (-)	35.76 (-)
Reach 4	NA	NA	NA
Reach 5	48.1 (13.73)	41.87 (0.40)	10.03 (13.45)
Reference Area	23.94 (11.70)	40.2 (11.02)	35.86 (16.34)

1 – Based on regression on ordered statistics (ROS). See Appendix E.
(-) – No standard deviation due to only one sample analyzed
NA – Not analyzed

Bayou Verdine sediment tended to have a higher percentage of clay particles than the reference area. Mean percentages of silt tended to be lower, with the exception of Reach 5, which was higher. Mean percentages of sand were similar, with the exception of Reach 5, which was lower. The higher percentage of clay particles may be indicative of the amount of rural drainage in Reach 5.

8.4.1.2 Total Organic Carbon

TOC provides an indication of the total organic material present and includes the carbon both from naturally occurring organic material and from organic chemical contaminants. TOC in sediment was measured in both Phase I and Phase II. The mean TOC concentration for the entire bayou was approximately 24,327 mg/Kg, with a standard deviation of 56,635 mg/Kg. The coefficient of variation was 2.3, indicating the concentrations were highly variable within the bayou. Highest mean values were within Reach 2 but had a range of TOC values from 9,710 mg/Kg to 424,500 mg/Kg. Reaches 1, 3, and 5 had similar values, with low coefficient of variation, and Reach 4 exhibited the lowest concentrations. Exhibit 8-8 lists the mean concentrations by reach and compares them to reference area conditions.

Exhibit 8-8 Bayou Verdine Mean[1] (Standard Deviation) TOC

Reach of Bayou Verdine	TOC (mg/Kg)	Reference Area
Reach 1	20,568 (16,686)	
Reach 2	48,708 (107,448)	
Reach 3	16,572 (7,305)	43,356 (24,874)
Reach 4	6,524 (3,322)	
Reach 5	11,950 (3,172)	

1 – Based on ROS. See Appendix E

TOC concentrations tended to be lower than the reference area, with the exception of Reach 2.

8.4.2 Surface Water Characteristics

Surface water characteristics are presented in this section comparing to reference area conditions.

8.4.2.1 Total Dissolved Solids

Dissolved solids refer to any minerals, salts, metals, cations, or anions that may be dissolved in the estuarine water. Sources of dissolved solids may be from soil erosion, waste discharge, saltwater intrusion, urban runoff, eroding stream banks, and stirred-up bottom sediments from activities such as dredging. In addition to measuring total dissolved solids, salinity and conductivity were measured to describe the conditions within the bayou. Salinity and conductivity are related and essentially equivalent through conversion factors.

Salinity is the measure of the amount of dissolved salts in the surface water. Salinity levels control to some degree the types of animals and plants that may live in a particular area of the estuary. Salinity measurement is also important in determining if dissolved organic carbon will precipitate or "salt out."

Conductivity estimates the amount of total dissolved ions in water. Conductivity is controlled by geology, size of the watershed, evaporation rates, and other sources of ions to the bayou such as wastewater, saltwater intrusion, or urban and agricultural runoff. An increase in conductivity could signal the introduction of a wastewater or runoff source or a saltwater influence.

Mean values for TDS were similar for Bayou Verdine and the reference area. The reference area exhibited a greater range, possibly due to agricultural or urban runoff or saltwater intrusion (entrained tidal surge) due to closer proximity to the Gulf of Mexico.

Exhibit 8-9 Total Dissolved Solids (mg/L) in Bayou Verdine and the Reference Area

Parameter	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation
TDS[2] in Bayou Verdine	3,500	20,000	11,967	7,738
TDS[2] in Reference Area	6,000	32,000	13,467	10,245

1 – Values based on ROS. See Appendix E.
2 – Results from Phase II only

Salinity values were recorded during Phase II at each of the SQT sample locations. Salinity varied from 2 to 21.5 ppt, with the highest salinity located in Reach 1 and then decreasing to below 5 ppt in Reach 2 (possibly due to fresh water inflow from Vista West, Faubacher, or KCSRR Ditches). Reach 5 was primarily fresh water, with salinity values approaching zero. Based upon the USFWS salinity classification system, there are four types of salinity systems in Bayou Verdine. Reach 1 would be classified as polyhaline (18 to 30 ppt) near the confluence of the Calcasieu River and changing to mesohaline (5 to 18 ppt) near I-10. Reach 2 is an oligohaline (0.5 to 5 ppt) system. Salinity measurements were not taken within Reaches 3 and 4, but it is assumed that they become more of a fresh water system as Reach 5 is classified as a fresh water system (0 to 0.5 ppt). Exhibit 8-10 presents summary statistics of the salinity for Bayou Verdine and the reference area.

Exhibit 8-10 Salinity (ppt) Levels in Bayou Verdine and Reference Area

Parameter	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation
Salinity[2] in Bayou Verdine	2	21.5	13	9
Salinity[2] in Reference Area	6	36	14	12

1 – Values based on ROS. See Appendix E.
2 – Results from Phase II only.

Salinity was slightly higher in the reference area most likely due to its closer proximity to the Gulf of Mexico and the lack of freshwater sources into the reference areas.

Conductivity levels were highest (greater than 30,000 µS/cm) in Reach 1 with concentrations less than 10,000 µS/cm throughout the rest of the bayou, generally consistent with salinity values. Mean conductivity levels were higher in the reference area most likely due to the higher salinity levels. Exhibit 8-11 presents summary statistics for conductivity.

Exhibit 8-11 Conductivity (µs/cm) in Bayou Verdine and the Reference Area

Parameter	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation
Conductivity[2] in Bayou Verdine	547	33,450	9,062	13,357
Conductivity[2] in Reference Area	1,350	53,800	21,363	18,967

1 – Values based on ROS. See Appendix E.
2 – Results from Phase II only.

8.4.2.2 Hardness

Hardness is the measure of multivalent cations and is proportional or equivalent to the concentration of calcium and magnesium concentration of the water. Generally, as hardness increases, toxicity decreases. Hardness was measured as calcium carbonate ($CaCO_3$) in water samples in Reaches 1 through 4, with values increasing downstream toward the mouth of Bayou Verdine. The downstream portions of the bayou (Reaches 1 and 2) are considered very hard based on U.S. Department of Interior and Water Quality Association standards (> 180 mg/L). The rest of the bayou ranges from moderately hard (between 60 and 120 mg/L) to hard (120 to 180 mg/L). The average fresh water value for southern Louisiana is 140 mg/L (USACE 1998). Hardness values are shown in Exhibit 8-12.

Exhibit 8-12 Hardness, as $CaCO_3$, (mg/L) in Bayou Verdine and Reference Area

Parameter	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation
Hardness[2], as $CaCO_3$ in Bayou Verdine	80	246	128	58
Hardness[2], as $CaCO_3$ in Reference Area	1,295	1,295	-	-

1 – Values based on ROS. See Appendix E.
2 – Results from Phase I only

Hardness was significantly higher in the reference area than in Bayou Verdine, indicating higher concentrations of calcium and magnesium in the reference areas.

8.4.2.3 Alkalinity and pH

Increases or decreases of pH may be an indication of anthropogenic effects such as wastewater discharge, freshwater recharge, groundwater input, or contamination from urban or agricultural runoff. Measurement of pH may isolate a particular area that might be receiving discharges from these sources. Alkalinity is the measure of a solution's resistance to changes in pH, i.e., buffering capacity. Typically, water with a high alkalinity will resist the adverse affects of acidic contamination. The higher the alkalinity, the less likely an acidic (natural or manmade) constituent will be to cause a significant change in pH.

Surface water pH values in Bayou Verdine ranged from 7.26 to 8.15 standard units, which is considered neutral. Within Bayou Verdine, total alkalinity values ranged from 85 to 191 mg/L. Highest alkaline values are in Reach 2 and just downstream of I-10, and overall concentrations were greater than in the reference areas. Exhibits 8-13 and 8-14 summarize the pH and alkalinity, respectively, conditions present in Bayou Verdine and the reference area.

Exhibit 8-13 pH (standard units) Levels in Bayou Verdine and the Reference Area

Parameter	Minimum Detected Value	Maximum Detected Value	Median[1]
pH[2] in Bayou Verdine	7.26	8.15	7.51
pH[2] in Reference Area	6.67	8.135	7.27

1 – Values based on ROS. See Appendix E.
2 – Results from Phase II only

Exhibit 8-14 Total Alkalinity (mg/L) in Bayou Verdine and the Reference Area

Parameter	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation
Total Alkalinity[2] in Bayou Verdine	85	191	126	41
Total Alkalinity[2] in Reference Area	42.1	42.1	-	-

1 – Values based on ROS. See Appendix E.
2 – Results from Phase I only (1 result).

The reference area exhibited a broader range in pH values than in Bayou Verdine but had similar mean values. The alkalinity was higher in Bayou Verdine, indicating a greater potential to neutralize acidic inputs.

8.4.2.4 Nitrogen

Nitrogen was measured as TKN and ammonia. Nitrate and nitrite are inorganic ions occurring naturally as part of the nitrogen cycle (Smith, 1990). TKN is the organic form of nitrogen and includes both the dissolved and particulate form, whereas ammonia is the dissolved form of nitrogen. Ammonia, at low levels, is an important nutrient for estuarine organisms, whereas it becomes toxic at high concentrations. In contrast to freshwater systems where phosphorous is the limiting nutrient factor, nitrogen is the primary limiting nutrient in the seaward portions of most estuarine environments (Paerl 1993). If high levels of nitrogen are introduced into the estuary, a significant increase of algae or large aquatic plants may occur NOAA/EPA (1988) suggests that nitrogen levels to avoid algae blooms to be between 0.1 and 1 mg/L.

TKN, the summation of ammonia and organic nitrogen, was similar in the shallow lake and ship channel energy system to what was observed in the reference areas. Exhibit 10-15 summarizes TKN results for Phase I and Exhibit 10-16 presents the summary statistics for ammonia.

Exhibit 8-15 TKN (mg/L) in Bayou Verdine and the Reference Area

Parameter	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation
TKN[2] in Bayou Verdine	0.51	0.85	0.56	0.15
TKN[2] in Reference Area	0.95	0.95	-	-

1 – Values based on ROS. See Appendix E.
2 – Results from Phase I only.

Exhibit 8-16 Ammonia, as N, (mg/L) in Bayou Verdine and the Reference Area

Parameter	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation
Ammonia[2] as N in Bayou Verdine	0.11	0.26	0.11	0.08
Ammonia[2] as N in Reference Area	0.0064	0.0064	-	-

1 – Values based on ROS. See Appendix E.
2 – Results from Phase I only

The one result of TKN was slightly higher in the reference area, whereas the ammonia levels were significantly lower. The higher ammonia levels that were present in Bayou Verdine may be the result of wastewater input.

Ammonia concentrations were higher than what was observed in the reference areas. According to EPA (1989b), the criteria maximum concentrations (CMC) for total ammonia for pH, temperatures and salinity found in Bayou Verdine range from 44 to 50 mg/L. The criteria continuous concentrations (CCC), according to EPA (1989b), range from 6.6 to 12 mg/L. Ammonia levels were below the CMC and CCC values for Bayou Verdine.

8.4.2.5 Dissolved Oxygen

Dissolved oxygen is typically an indicator of high quality for aquatic life and helps determine the ability of aerobic organisms to survive. The concentration is dependent upon temperature, salinity, wind, water turbulence, atmospheric pressure and presence of oxygen demanding compounds and organisms, and photosynthesis. The percent saturation is the measured dissolved oxygen level divided by the greatest amount of oxygen that the water can hold at that temperature and atmospheric conditions. Low dissolved oxygen levels typically indicate an excessive demand on the system from organic material deposited from pollution sources or from natural sources such as leaves and grass. Exhibit 8-17 summarizes the DO in Bayou Verdine and the reference area.

Exhibit 8-17 Dissolved Oxygen, in Percent Saturation in Bayou Verdine and the Reference Area

Parameter	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation
Dissolved Oxygen[2] (%) in Bayou Verdine	5.09	18.47	11.20	5.09
Dissolved Oxygen[2] (%) in Reference Area	7.50	12.76	10.36	1.55

1 – Values based on ROS. See Appendix E.
2 – Results from Phase II only

Dissolved oxygen levels exhibited a smaller range in the reference area, but mean percentages were similar. Typically, values over 80 percent represents high quality water, which will support various flora and fauna, whereas values less than 80 percent indicate poor water quality conditions.

8.4.3 Porewater

Porewater is the water occupying space between sediment particles. DOC, salinity, conductivity, hardness, total alkalinity, ammonia as N, unionized ammonia, and pH were measured at 10 sample locations in Bayou Verdine. DOC and salinity are presented in this section, whereas discussion of the other parameters is presented in the BERA.

8.4.3.1 Dissolved Organic Carbon

Dissolved organic carbon (DOC) is the organic fraction of carbon in water that is filterable. DOC plays a role in the fate and transport of trace elements in the subsurface as well as influences the bioavailability of hydrophobic compounds. In saline environments, dissolved organic matter is precipitated from the water to the sediment phase where it can effectively sorb hydrophobic chemicals (Chapman et al 2001). Exhibit 8-18 summarizes the porewater dissolved organic carbon levels in Bayou Verdine and the reference area.

Exhibit 8-18 Porewater DOC (mg/L) in Bayou Verdine and the Reference Area

Parameter	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation
DOC[2] in Bayou Verdine	1.60	5.33	3.15	1.13
DOC[2] in Reference Area	2.29	13.52	4.78	3.41

1 – Values based on ROS. See Appendix E.
2 – Results from Phase II only

Within Bayou Verdine, DOC had a coefficient of variation of 0.36, signifying that values did not vary greatly throughout the bayou. The maximum detected value was located in Reach 2, which corresponds to the high TOC found in sediment in the same reach. Mean DOC concentrations were slightly higher in the reference areas most likely due to the vegetation surrounding the water body.

8.4.3.2 Salinity

As discussed previously, salinity and conductivity are measures of TDS in water. Salinity values are presented in Exhibit 8-19.

Exhibit 8-19 Porewater Salinity (ppt) in Bayou Verdine and the Reference Area

Parameter	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation
Salinity[2] in Bayou Verdine	2	50	15.3	15.7
Salinity[2] in Reference Area	12	24	17.1	3.8

1 – Values based on ROS. See Appendix E.
2 – Results from Phase II only

Porewater salinity values were comparable with reference area conditions, although varied significantly more. However, salinity in the porewater within Bayou Verdine was high in comparison to overlying surface water salinity, which had a mean value of 13 ppt. Highest porewater salinity concentrations were located in Reach 1 and consistently decreased upstream in the remaining reaches. The difference between salinity measurements between surface water and porewater are most likely related to sediment type and duration of exposure (Chapman et al 2001). Equilibrium between surface water and porewater is slow in sediments containing high amounts of fine particles such as clay and silt (Chapman et al 2001).

8.5 Nature and Extent for the Bayou Energy System

The results and discussion section is organized into four sections: COPCs identified for the bayou energy system (Section 8.5.1), the results of the PCA (Section 8.5.2), and contaminants that showed little or no correlation to other contaminants or parameters (Section 8.5.3).

Graphical presentation will illustrate the concentrations of an indicator variable that will be representative of the other parameters or constituents in that factor. Key contaminants that were not presented in a factor will be presented in individual figures.

Appendix E provides details of the PCA and complete summary statistics for all compounds detected in the bayou energy system in Bayou d'Inde.

8.5.1 COPCs for the Bayou Energy System in Bayou Verdine

To focus on the COPCs that are the primary risk drivers, energy system specific COPCs were selected for discussion. These energy system specific COPCs were identified by comparing the primary risk drivers from the HHRA and the BERA and comparing those COPCs to reference area conditions. Section 8.5.1.1 presents the results of the statistical comparison of these COPCs between energy system and reference area. Section 8.5.1.2 presents the bayou energy system COPCs identified.

8.5.1.1 Comparison to Reference Areas

Results of the WRS test are presented in Table 8-8. Contaminants that were determined to be statistically significant different than the reference area are:

- PAHs
- PCBs
- Inorganics (arsenic, barium, mercury, and zinc)

8.5.1.2 COPCs Selection

Energy system specific COPCs for the bayou energy system in Lower Calcasieu were selected by determining if the COPC is a risk driver in the HHRA or the BERA and was determined to be statistically significant different than reference area conditions (Table 8-9). The following COPCs were selected for the bayou energy system in Lower Calcasieu:

- VOCs (1,2-dichloroethane and trichloroethane)

- PAHs (as low and high molecular weight PAHs)
- PCBs
- Inorganics (barium, mercury, and zinc)

The extent as well as the fate and transport of these COPCs will be discussed in Sections 8.5.2 (PCA) and 8.5.3 (Isolated Chemistry).

8.5.2 PCA

The PCA revealed four dominant factors that accounted for most of the variability (83 percent) in surface sediment within Bayou Verdine. These factors are:

- Medium to high level contamination due to dioxins, PAHs, and metals (Dioxin/PAH/Metal factor) that accounted for 31 percent of the variance.
- Background metals (Background Metal factor) that accounted for 16 percent of the variance.
- Medium to high level contamination due to pesticides, VOCs, SVOCs, metals (Pesticide/VOC/SVOC/Metal Factor) that accounted for 15 percent of the variance.
- Medium to high level furan/dioxins and metals (Furan/Dioxin/Metal Factor) that accounted for 21 percent of the variance.

These factors present groups of parameters and/or contaminants that tend to correlate with each other and explain variability in the data set.

8.5.2.1 Dioxin/PAH/Metal Factor

This section presents the extent of the dioxin/PAH/metal factor (Factor 1) and discussion as to the primary fate and transport process for contaminants in this factor.

8.5.2.1.1 Results

The Dioxin/PAH/Metal factor is comprised of metals, PAHs, and dioxins, as well as TOC and pH in sediment. The key parameters, based on highest correlation, were lead, chromium, copper, 1,2-benzphenanthracene, benzo(b)fluoranthene, fluoranthene, and pyrene. TOC and pH also correlated within this factor. This factor controls 31 percent of the variance in the bayou. Parameters such as TOC, pH, and sodium (and other cations) are also contained in this factor. These parameters control the mobility and the fate and transport of chemicals in this group. Summary statistics for the parameters that group within this factor are presented in Exhibit 8-20 through 8-22.

Exhibit 8-20 Summary Statistics of Inorganics (mg/Kg) in Dioxin/PAH/Metal Factor in Surface Sediment

Parameter	Frequency of Detects	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation	Coefficient of Variation
Mercury	37/101	0.0239	0.57	0.14	0.15	1.08
Lead	101/101	6.2	139	25.0	20.7	0.83
Sodium	25/25	110	8,660	1,418	2,320	1.64
Aluminum	25/25	3,390	13,400	7,513	3,189	0.4
Copper	95/101	2.8	317	42	65	1.5
Cyanide	3/25	0.36	1.4	-	-	-
Chromium	91/91	3.2	1,240	109	198	1.82

1 – Values based on ROS. See Appendix E.
(-) – Mean value is not calculated for less than 20% detected due to estimation of distribution becomes less accurate.

Exhibit 8-21 Summary Statistics of PAHs/SVOCs (µg/Kg) in Dioxin/PAH/Metal in Surface Sediment

Parameter	Frequency of Detects	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation	Coefficient of Variation
Pyrene	72/98	17	160,000	10,370	23,924	2.3
Fluoranthene	53/98	69	40,000	3,152	6,915	2.2
Benzo(a)anthracene	52/98	65	53,000	3,964	8,580	2.2
Benzo(b)fluoranthene	58/98	43	58,000	4,118	8,702	2.1
1,2-Benzphenanthracene	67/98	100	120,000	9,510	19,214	2.0
Benzo(a)pyrene	47/98	120	71,000	5,006	12,108	2.4
Benzo(k)fluoranthene	17/98	25	3,600	-	-	-
Dibenzo(a,h)anthracene	19/98	150	9,800	-	-	-
Diesel Range Organics	9/9	18,500	14,000,000	2,905,833	5,260,472	1.8

1 – Values based on ROS. See Appendix E.
(-) – Mean value is not calculated for less than 20% detected due to estimation of distribution becomes less accurate.

Exhibit 8-22 Summary Statistics of Dioxins (ρg/g) in Dioxin/PAH/Metal in Surface Sediment

Parameter	Frequency of Detects	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation	Coefficient of Variation
Total HpCDD	11/11	41	6,300	1,077	2,215	2.1
OCDD	11/11	280	25,000	5,440	8,222	1.5
Total HxCDD	11/11	4.7	490	107	161	1.5
Total TCDD	11/11	0.8	37	10	14	1.5
Total HpCDF	11/11	5.1	2,800	608	939	1.5

1 – Values based on ROS. See Appendix E.

Lead was used as the indicator variable for this factor.

Surface Sediment

Figure 8-4 presents the results of lead as an indicator parameter for the dioxin/PAH/metal factor. These groups of contaminants were prevalent in Reaches 1 and 2, with elevated concentrations and tend to decrease from the rail spur in Reach 2 upstream. Figure 8-4 indicates that contamination is highest downstream of the Vista West Ditch and just upstream of I-10 in Reach 2.

Dioxin, reported as 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD TEQ), was detected in Reaches 1 through 5 (Figure 8-5). The highest concentrations were detected in Reach 2, with elevated concentrations approximately 180 m downstream of the Vista West Ditch and approximately 60 m upstream of I-10.

PAHs in Factor 1 are located from the rail spur in middle Reach 3 through upper Reach 1. Highest concentrations are located downstream of the KCSRR Ditch to I-10.

The metals chromium, copper, lead, and mercury were found in multiple locations in the bayou, with elevated concentrations located primarily in Reaches 1 and 2. Highest concentrations were found in Reach 2 from Vista West Ditch to approximately 250 m downstream and from the Faubacher Ditch to I-10.

Subsurface Sediment

Both metals (chromium, copper, lead, and mercury) and PAHs (1,2-benzphenanthracene, benzo(a)anthracene, benzo(b)anthracene, fluoranthene, and pyrene) were detected in subsurface sediments. Dioxin was not measured in any subsurface samples. BVR2007 exhibited the highest concentrations for both metal and PAH concentrations (Figure 8-4). Concentrations tended to decrease both upstream and downstream with various depths having higher concentrations depending on the COPC. In Reaches 1 and 2, metals concentrations are typically higher in surface sediment than in the subsurface, with the exception of chromium, which was higher in the 30 to 45-cm interval. In Reach 3, the 15 to 30-cm interval tended to have the higher concentrations, with chromium exceeding surface concentration by a factor of six. Reach 4 showed metal concentrations decreasing in the subsurface.

PAH concentrations at BVR1011 and BVR2007, which had the highest concentrations in the surface and subsurface sediment, did not vary significantly with depth. Similar to metals, individual PAHs concentrations were variable with depth either decreasing or increasing in the subsurface. Pyrene was the most widely detected PAH in the subsurface. PAH concentrations tended to decrease in the subsurface in Reaches 1 and 2, with the 15 to 30-cm depth interval having higher concentrations in Reaches 3 and 4.

Surface Water

Mercury was detected in surface water samples collected in the bayou energy system in Lower Calcasieu. Exhibit 8-23 presents the total and dissolved (if detected) concentrations of these contaminants and compares them to EPA AWQC (Ambient Water Quality Regulations; as published in the Federal Register 1995) CCC (chronic) and CMC (acute) values and/or LDEQ Water Quality Regulation (LDEQ 2000) for both freshwater and marine environments. For systems with salinity between 1 and 10 ppt, the more stringent of either fresh or marine values should be used to compare with mean dissolved concentrations. In cases where the dissolved phase was not detected, the surface water criteria for that contaminant was converted to an unfiltered criterion using a conversion factor provided in LDEQ 2000.

Exhibit 8-23 Mean & Standard Deviation of Total and Dissolved Concentrations (mg/L) in Dioxin/PAH/Metal Factor in Surface Water, Bayou Energy System

Analyte	Mean Total[1]	Mean Dissolved[1]	Fresh Acute	Fresh Chronic	Marine Acute	Marine Chronic
Mercury	ND	0.000271	0.0017[2]	**0.00001[2]**	0.0017[3]	**0.000021[3]**

1 – Based on ROS. See Appendix E. If only two samples, an average was calculated. ND: Not Detected
2 – LDEQ Water Quality Regulations based on 200 mg/L hardness for dissolved concentrations.
2 – LDEQ Water Quality Regulations based on 50 mg/L hardness for dissolved concentrations.

Mercury exceeded both the fresh and marine water surface water criteria. Mercury was detected in 4 of 11 stations with a maximum concentration observed of 0.0006 mg/L at station BVR3C1WM (in Reach 3).

8.5.2.1.2 Discussion

This section interprets the results of the factor analysis as a group and by individual contaminant groups (i.e., organics and inorganics).

Factor 1 includes parameters that are the result of releases of contamination into the AOC. The mean concentrations of all the parameters in this group are relatively high. The coefficient of variation is also very high for this group of chemicals, indicating a high level of variability and large range of concentrations (i.e., selected locations will have very high concentrations). This observation also indicates releases of contamination because very small to very high concentrations are present in the AOC. PAHs in this group are the high molecular weight PAHs (HPAHs).

The correlation with TOC, cations, and pH indicate that contaminants were released into the water phase and were subsequently removed to the sediments by adsorption processes, precipitation, or salting out. The most likely cause would be salting out, a controlling process throughout most of the bayou as evidenced by the high sodium concentrations in sediment and porewater salinity. Removal to the sediments appears to occur in Reaches 1 through 3. Accumulation of these adsorbed sediments may occur upstream of I-10 prior to flow through concrete culverts beneath the interstate. The culverts may act to slow surface water velocities, allowing contaminants that have adsorbed to fine particles to settle. In addition, visual inspection of this area shows that the bayou widens slightly, creating a settling pool during normal flows or a surge pond during storm events.

Organics

Hydrophobic compounds, such as dioxins and PAHs, tend to sorb to organic matter in the sediment as shown by the high concentrations of TOC within Reach 2. Normalizing these compounds to TOC showed that the HPAHs are dominant in the bayou, with elevated concentrations throughout Reach 2 and an area in Reach 1 from 315 to 1,000 m upstream of the mouth of the bayou. HPAHs are generally immobile in terms of chemical transportation. The compounds in this group bind tightly to sediments, and transport appears to occur only by physical movement or migration of the sediments. The variable TOC concentrations in the bayou indicate that the sediments are disturbed, possibly re-suspended and mobilized downstream. The compounds in this group bind tightly to sediments, and transport appears to occur only by physical movement or migration of the sediments.

Historically, Reaches 1 and 2 have had high PAH contamination according to the 1993 EPA study and the 1993-94 PPG study. PPG, Conoco, Sasol (formerly CONDEA), and Tetra have formerly violated discharge limits by potentially releasing crude, slurry and sweet gas oils, chlorinated hydrocarbons, gasoline, and diesel (Tables 7-1, and 8-1 through 8-4).

Diesel range organics (DRO) analyses indicate elevated concentrations in the area upstream of I-10, near the KCSRR West Ditch. The DRO analytical procedure is a gas chromatograph (GC)/flame ionization detector (FID) method that reports combined concentrations of long chain hydrocarbons, ranging from C9 through C22. This range encompasses the lighter aliphatics and heavier aromatics (from benzene to benzo [g,h,i]perylene). The DRO values measured indicate that longer chain hydrocarbons are present in addition to the aromatics measured by GC/mass spectrometer analytical methods. These heavier compounds are typical components of coke oil or other heavy oils. The source of contamination to these locations may be the Conoco Coke production process or diesel fuels and/or motor oils associated with KCSRR operations.

The source of PAHs is probably located near BVR1011 and BVR2007. This observation is based on the high concentrations present in the subsurface (Figure 8-4). Concentrations in both BVR1011 and BVR2007 did not vary significantly in comparison to other stations, indicating that physical movement of sediment has not affected these locations. Concentrations of PAHs in the subsurface decreased up and downstream of these locations. Stations such as BVR3007 had higher concentrations in the 15 to 30-cm depth interval, indicating that PAHs may have settled fine-grained particles in the bayou and eventually were covered by sedimentation.

Dioxins are very persistent in the aquatic environment. Dioxins have very low water solubility and sediments are a common reservoir for dioxins. In the aquatic environment, dioxins strongly adsorb to sediments and are highly soluble in lipids. Various biological studies have demonstrated that TCDD is generally resistant to biodegradation although TCDD in exposed sediments may be susceptible to photodegradation. Without photodegradation, half-life in deeper soils may be as long as 12 years (EPA 1993).

Dioxin, when normalized to TOC, has the highest concentrations downstream of the Vista West Ditch and decreases upstream from Reach 2. Dioxin concentrations tend to decrease slightly to I-10 where elevated concentrations were detected both upstream and downstream of the I-10 culverts. Dioxins are typically produced from either the combustion of chlorinated organic compounds and chlorination of aromatic compounds. Sources of dioxins into Bayou Verdine include, but are not limited to, atmospheric deposition or chlorination of wastewater effluent. Since the values vary widely in the bayou and tend to concentrate in Reach 2, a possible source is from discharge of wastewater effluent from Vista West Ditch.

Inorganics

Metals contamination (copper, chromium, lead, and mercury) was found throughout the bayou. Elevated concentrations were noted in Reaches 1 and 2 and in isolated locations in Reach 3. Highest median and detected concentrations were found in Reach 2 for all four metals and tended to decrease upstream and downstream for this reach (although only slightly for mercury). Metals correlate with each other, indicating they are easily transported within the bayou and out into the Calcasieu River. Highest metals concentrations are located downstream of Vista West Ditch, at BVR2C1SS, indicating that the ditch is a possible source.

Behavior of copper, chromium, and lead is dictated by metal compound; oxides, carbonates, hydroxides, and sulfides are most commonly formed in the environment. Formation of these compounds depends upon water concentration and pH. The result is removal of the metals from the dissolved phase and evorporation into the sediments. However, lead and copper can also be more soluble in higher salinity waters due to chloride complexing.

Salinity affects major cations (sodium, calcium, etc.) because of increased ionic strength of the solution, which reduces activity of the species in solution. The result is increased solubility and decreased partitioning compared to freshwater. Saline water ions can also compete with metals for adsorption sites on sediments. Hanor and Chan in 1979 found that ion exchange between magnesium from seawater and adsorbed barium occurred in the mixing zone of the Hudson River, mobilizing barium. This effect may be present at the confluence of the major ditches in Reach 2.

Elemental metals such as copper and lead typically are not directly affected by changes in reduction/oxidation potential. Exceptions include chromium and arsenic. For example, chromium is usually discharged as a Cr^{6+} anion (usually CrO_4^{2-} depending upon pH and ORP). However, the Cr^{6+} is converted to Cr^{3+} in sediments and then the precipitates on a hydroxide or non-chromium oxyhydroxide. Adsorption onto particulate matter may also act as an important transport mechanism. Sorption of zinc and similar metals by hydrous metal oxides, clay minerals, and organic materials may be an important fate process in the aquatic environment, resulting in enriched suspended loads and bed sediment relative to the water column. Where suspended solids make up a high proportion of the total solids load, most of the zinc transported will be sorbed to the suspended and colloidal particles (Kubota *et al.* 1974). TSS load within the water column can be an effective means of transporting many otherwise immobile compounds. Limited TSS data in Bayou Verdine make it difficult to assess the variability of the sediment load across the reaches but seem to indicate that sediment load transport may be effective in metals distribution.

Iron and manganese oxidation in areas of increased DO remove chromium, copper, lead, and zinc via co-precipitation. King (1998) found that when ferrous iron, present in river flow, mixed with higher DO, pH, and alkalinity seawater within an estuary the iron led co-precipitation of a suite of other metals. Given the surface runoff source of much of the freshwater input to the more saline water of Bayou Verdine, co-precipitation is considered an ongoing process across the bayou. The broad occurrence and range of detections support this interpretation.

Copper, chromium, lead, and mercury in the subsurface indicate that the possible sources may be the same as those associated with PAH contaminants.

8.5.2.2 Background Metals

This section presents the extent of the background metals factor (Factor 2) and discussion as to the primary fate and transport processes controlling behavior of contaminants in this factor.

8.5.2.2.1 Results

Surface Sediment

The Background Metals factor is composed of metals that are comparable to reference area conditions. Summary statistics of constituents in this factor are presented in Exhibit 8-24.

Exhibit 8-24 Summary Statistics of Metals (mg/Kg) in Background Metal Factor in Surface Sediment

Parameter	Frequency of Detects	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation	Coefficient of Variation
Iron	25/25	74	16,000	808	2,226	0.64
Beryllium	26/91	0.23	1.5	0.4	0.3	0.79
Potassium	24/25	292	1,720	717	382	0.53
Cobalt	22/25	2.1	38.4	7.6	8.9	1.18
Magnesium	25/25	559	5,000	1,775	1,155	0.65
Manganese	25/25	101	1,860	348	408	1.17
Vanadium	91/91	7.7	85.4	19.1	10.9	0.57
Barium	91/91	28.3	365	155	64	0.41

Arsenic	89/91	0.86	18.7	3.9	2.6	0.66

1 – Values based on ROS. See Appendix E.

8.5.2.2.2 Discussion

These metals typically represent background conditions.

8.5.2.3 Pesticide/VOC

The Pesticide/VOC factor was the third factor to account for the variability in surface sediment. The results and discussion of contaminants in this factor in Bayou Verdine are presented in this section.

8.5.2.3.1 Results

This factor groups pesticides, 1,2-dichloroethane (EDC), and thallium within this factor. Exhibit 8-25 through 8-27 presents the summary statistics for these contaminants.

Exhibit 8-25 Summary Statistics of Pesticides (µg/Kg) in Pesticide/VOC Factor in Surface Sediment

Parameter	Frequency of Detects	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation	Coefficient of Variation
Aldrin	5/70	2.6	3.1	-	-	-
Beta-BHC	3/70	3.4	57	-	-	-
4,4’-DDT	4/70	4.8	48	-	-	-
Delta-BHC	6/70	4.6	55	-	-	-

1 – Values based on ROS. See Appendix E.
(-) – Mean value is not calculated for less than 20% detected due to estimation of distribution becomes less accurate.

Exhibit 8-26 Summary Statistics of Organics (µg/Kg) in Pesticide/VOC Factor in Surface Sediment

Parameter	Frequency of Detects	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation	Coefficient of Variation
EDC	17/105	15	19,000,000	-	-	-
Bis(2-chloroethyl)ether	3/101	630	49,000	-	-	-

1 – Values based on ROS. See Appendix E.
(-) – Mean value is not calculated for less than 20% detected due to estimation of distribution becomes less accurate.

Exhibit 8-27 Summary Statistics of Metals (mg/Kg) in Pesticide/VOC Factor in Surface Sediment

Parameter	Frequency of Detects	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation	Coefficient of Variation
Thallium	7/91	0.54	1.9	-	-	-

1 – Values based on ROS. See Appendix E.
(-) – Mean value is not calculated for less than 20% detected due to estimation of distribution becomes less accurate.

EDC was used as an indicator variable for this factor.

Surface Sediment

Elevated concentration of contaminants grouped in this factor was primarily located in the middle reaches of Bayou Verdine (Figure 8-6). Highest concentrations were located within close proximity of Vista West Ditch in Reaches 2 and 3. For EDC, in particular, approximately 120 m of bayou are highly contaminated (80 m upstream and 40 m downstream of Vista West Ditch).

Within the other areas of Bayou Verdine, pesticides, EDC, or thallium were detected at low concentrations or not at all.

Subsurface Sediment

EDC was detected in the subsurface at station BVR3007. In the 15 to 30-cm interval, BVR3007 was reported to have a concentration of 20 µg/Kg.

Surface Water

Contaminants grouped within this factor were not detected in the surface water.

8.5.2.3.2 Discussion

Various VOCs indicative of chlorinated process byproducts are present in the sediments from the middle of Reach 3 to approximately 100 m downstream of Vista West Ditch in Reach 2 (Figure 8-6). Compounds with the greatest Frequency of Detects and/or concentration include EDC, tetrachloroethene (PCE), TCE, 1,2-DCE, chlorobenzene, 4-bromofluorobenzene, dibromofluromethane, and dichloromethane. Each of these VOCs is readily volatilized and degraded. The presence of PCE, TCE, and 1,2-DCE at, or downstream of, BVR2C3SS indicates ongoing biodegradation (anaerobic reductive dechlorination). The lack of large areal extent is to be expected given the volatile nature of the contaminants. The presence of the contaminants in the sediments at the elevated concentrations noted (location BVR2C3SS: PCE 38,000 µg/Kg; TCE 50,000; total 1,2-DCE 46,000) indicates deposition of material entrained in finer grained sediments and organic matter, limiting direct contact with the overlying waters and subsequent dissolution and volatilization.

EDC is present in the sediments at significant concentrations. The current findings may be related to EDC releases from former CONDEA Vista operations. Several historic releases may have flowed into the Vista West Ditch or impacted subsurface soil layers that intersect Bayou Verdine. The downstream extent is 27 µg/Kg at R2EDC10SS; the upstream extent is defined as non-detect (66U µg/Kg) at BVR3007 (Figure 8-5). Chemical degradation of halogenated alkanes is controlled by hydroxyl radicals. The presence of EDC in the anoxic sediments appears to be limiting exposure to hydroxyl radicals, preventing significant degradation. Subsequently, EDC undergoes anaerobic dechlorination to chloroethane (biologically remediated). The volatility of chloroethane limits its use as a definitive marker of this process; however, the significant concentrations of EDC observed indicate that it is not having substantial impact on this contaminated sediment.

Aldrin is a representative pesticide and can describe general pesticide behavior. Aldrin biodegrades slowly; however, it is not highly water soluble or expected to readily leach from soils. Aldrin has been classified as moderately persistent, having a half-life in soil ranging from 20 to 100 days, with high sorptive capability.

The broad low-level detection of pesticides indicates localized entry into the bayou from various locations, representative of normal use, not indicative of spills or accidental release.

8.5.2.4 Furan/Dioxin/Metal

The Furan/Dioxin/Metals factor was the fourth factor to account for the variability in surface sediment. The results and discussion of furans detected in Bayou Verdine are presented in this section.

8.5.2.4.1 Results

Exhibits 8-28 and 8-29 present the results of the contaminants that comprise the furans/dioxin/metals factor. This factor includes the chlorinated furans octachlorodibenzo-furan (OCDF), pentachlorodibenzo-furans (PeCDFs), heptachlorodibenzo-furans (HpCDFs), hexachlorodibenzo-furans (HxCDFs), and tetrachlorodibenzo-furans (TCDFs). In addition, pentachlorodibenzo-p-dioxin (PeCDD), nickel, zinc, and calcium correlated in this factor.

Exhibit 8-28 Summary Statistics of Dioxins/Furans (ρg/g) in Furan/Dioxin/Metal Factor in Surface Sediment

Parameter	Frequency of Detects	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation	Coefficient of Variation
Total PeCDF	8/11	3.6	410	86	138	1.61
OCDF	9/11	10	4,400	805	1,513	1.51
Total PeCDD	4/11	9.92	32	9	11	1.18
Total HpCDF	11/11	5.1	2,800	608	939	1.54
Total HxCDF	7/11	120	1,000	259	317	1.22
Total TCDF	11/11	0.8	37	10	14	0.87

1 – Values based on ROS. See Appendix E.

Exhibit 8-29 Summary Statistics of Metals (mg/Kg) in Furan/Dioxin/Metal Factor in Surface Sediment

Parameter	Frequency of Detects	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation	Coefficient of Variation
Nickel	84/101	3.3	117	19	21	1.09
Zinc	101/101	8	1,670	451	476	1.05
Calcium	25/25	1,870	39,400	7,054	9,749	1.38

1 – Values based on ROS. See Appendix E.
(-) – Mean values less than 20 percent are not calculated due to estimation of distribution becomes less accurate.

Nickel was used as the indicator variable for this factor.

Surface Sediment

Dioxin/furan and metal concentrations were detected primarily in Reaches 1, 2, and 3, with the most heavily contaminated area just upstream and downstream of Vista West Ditch from approximately BVR3007 to BVR2002 (Figure 8-7). Dioxin/furan and metals concentrations tend to decrease upstream and downstream from this area.

Subsurface Sediment

At multi-depth locations, zinc concentrations decreased in the subsurface. Highest concentration detected in the subsurface was at BVR3007 with a result of 562 mg/Kg. Nickel concentrations tended to decrease or not vary significantly in the subsurface, with the exception of BVR3007. The concentration at BVR3007 increased in the 15 to 30 cm interval, but was not detected at the deeper interval.

Dioxin/furans were not analyzed in the subsurface in Bayou Verdine.

Surface Water

Zinc, in the dissolved phase, was detected in Bayou Verdine in Reaches 1 and 2. Highest concentrations were located in Reach 1 and decreased upstream into Reach 2. Exhibit 8-30 compares mean values of dissolved zinc in surface water with criterion set forth by LDEQ. Mean concentrations of zinc exceeded both the marine surface water acute and chronic criterion.

Exhibit 8-30 Mean & Standard Deviation of Total and Dissolved Concentrations (mg/L) in Furan/Dioxin/Metal Factor in Surface Water, Bayou Energy System

Analyte	Mean Total[1]	Mean Dissolved[1]	Fresh Acute	Fresh Chronic	Marine Acute	Marine Chronic
Zinc	ND	0.18	0.205[2]	0.187[2]	**0.09[3]**	**0.081[3]**

1 – Based on ROS. See Appendix E. If only two samples, an average was calculated. ND: Not Detected
2 – LDEQ Water Quality Regulations based on 200 mg/L hardness for dissolved concentrations.
3 – LDEQ Water Quality Regulations based on 50 mg/L hardness for dissolved concentrations.

8.4.2.2.2 Discussion

TCDF in the water column can be expected to partition strongly to sediment and suspended particulate matter. TCDF sorbs strongly to soils and, based upon its high K_{oc} value, (see Table 5-1) it is expected to adsorb very strongly to organic matter and resist leaching. Bioconcentration in aquatic organisms may be significant. Based on a high K_{ow} value, TCDF is expected to accumulate in aquatic receptors (Gutenmann *et al.* 1992). Based on its structural similarity to dioxin, TCDF is expected to accumulate to high concentrations in aquatic and semi-aquatic mammals and fish-eating birds. Data are not available regarding the biological degradation of TCDF in soil (HSDB 1997). Concentrations are elevated but not as high as the constituents in the dioxin/PAH/metals factor, which may indicate that furans are less variable and have a smaller range of concentrations.

As discussed in the dioxin/PAH/metal factor, general precipitation (or co-precipitation) directly or with iron oxyhydroxides and sorption of zinc by hydrous metal oxides, clay minerals, and organic materials is the dominant fate in the aquatic environment, resulting in enriched suspended loads and bed sediment relative to the water column. Where suspended solids make up a high proportion of the total solids load, most of the zinc transported will be associated with the suspended and colloidal particles (Kubota *et al.* 1974). TSS load within the water column can be an effective means of transporting many otherwise immobile compounds. Limited TSS data in Bayou Verdine makes it difficult to assess the variability of the sediment load across the reaches, but the broad extent of metals indicate that sediment load transport may be effective in metals distribution.

Iron and manganese oxidation in areas of increased DO remove chromium, copper, lead, and zinc via co-precipitation. King (1998) found that when ferrous iron, (present in river flow) mixed with seawater (with higher DO, pH, and alkalinity) within an estuary, the iron led co-precipitation of a suite of other metals. Given the surface runoff source of much of the freshwater input to the more saline water of Bayou Verdine, co-precipitation is considered an ongoing process across the bayou. The broad occurrence and range of detections support this interpretation.

There were no spills or enforcement history identified for zinc in Bayou Verdine.

8.5.3 Isolated Chemistry

Several COPCs that were detected in 5 percent or greater of the samples did not group with the three major PCA factor groups previously discussed. These include:

- Low molecular weight PAHs (LPAHs)

These COPCs did not group with the other major factors for one or more of the following reasons:

- The Frequency of Detectsion is typically low
- The distribution of contamination was different than observed for the compounds for the three major factors

Each of these COPCs is discussed in the following sections

8.5.3.1 Low Molecular Weight PAHs

This section describes the low molecular weight PAHs (LPAHs) detected in Bayou Verdine.

8.5.3.1.1 Results

Surface Sediment

LPAHs (Exhibit 8-31) were detected in Bayou Verdine in isolated areas in Reaches 1 through 3. Highest concentration of LPAHs was located up and downstream of I-10, with the highest concentration of LPAHs at BVR2007, with a value of 108,300 µg/Kg (Figure 8-8).

Exhibit 8-31 Summary Statistics of Factor 1 PAHs (µg/Kg) in Surface Sediment

Parameter	Frequency of Detects	Minimum Detected Value	Maximum Detected Value	Mean[1]	Standard Deviation
LPAHs	59/88	60	108,300	12,234	24,538

1 – Values based on ROS. See Appendix E.

Subsurface Sediment

LPAHs were observed above 11,000 µg/Kg at various locations in Bayou Verdine (Figure 8-8). In Reach 1, concentrations tend to decrease with depth, with the exception of BVR1C1. Concentrations increased in the 15 to 30-cm depth, but were undetected in the 30 to 45-cm depth interval. Within Reach 2, concentrations increase with depth, with the exception of BVR2002. At station BVR2C1, LPAHs were undetected in the surface sediment and at the 30 to 45-cm interval, but was observed to have a concentration of 910 µg/Kg in the 15 to 30-cm interval. BVR3007, also was undetected in the surface sediment, but had a concentration of 4,300 µg/Kg in the 15 to 30-cm interval. Within Reach 4 at station BVR4004, LPAHs were detected at the surface and at the 30 to 45-cm interval, but was undetected in the 15 to 30-cm interval.

8.5.3.1.2 Discussion

LPAH contaminants appear to have entered Bayou Verdine near the Conoco Lube Tank Farm and from the North Docks of PPG. The greatest concentration is located between BVR3001 and R3AB02SS when normalized to TOC. The contaminated sediments appear to be relatively stable as the system is not routinely subjected to significant inflow (surface runoff or active outfalls), and salinity fluctuations appear to be minimal. Although the LPAHs occurrence is fairly well defined, LPAHs do occur throughout Reaches 1 through 3. When normalized to TOC, elevated LPAH values are in Reach 3 and at the North Docks. Acenaphthene should biodegrade rapidly under aerobic conditions in soil and water; biodegradation half-lives range from 1 to 60 days, respectively. However, acenaphthene may persist under anaerobic conditions. It has also been noted that high concentrations under aerobic conditions prove toxic to microorganisms preventing biodegradation.

LPAHs are not expected to hydrolyze or bioconcentrate in the environment; however, photolysis in direct sunlit media is possible. This may be an important factor if impacted sediments become dewatered and exposed to sunlight. The range of K_{oc} values indicate that LPAHs will be slightly mobile in soil, with moderate leaching potential. However, primary transport of these chemicals appears to be the result of physical mechanisms, such as scouring and stream flow turbulence, as opposed to chemical desorption or dissolution. Many of the LPAHs are soluble in a number of organic solvents (methanol, ethanol, benzene, toluene, etc.) but relatively insoluble in water. LPAHs are susceptible to oxidation by ozone, peroxides, and other oxidants

(EPA 1987). LPAH affinity for organic carbon controls behavior in water as well. The compounds will likely adsorb to particulate matter, enabling transport.

Historically, Reaches 1 and 2 have had high PAH contamination according to the 1993 EPA study and the 1993-94 PPG study. PPG, Conoco, Sasol (formerly CONDEA), and Tetra have formerly violated discharge limits by potentially releasing crude, slurry and sweet gas oils, chlorinated hydrocarbons, gasoline, and diesel (Tables 7-1, and 8-1 through 8-4). Of particular importance is the high concentration (14,000,000 µg/Kg) of diesel range organics in Reach 2 south of KCSRR Ditch and upstream of I-10.

8.6 Summary and Conclusions

This section summarizes the COPCs found in Bayou Verdine and presents an overview of their relation to historic data, reference areas results, spatial distribution, sediment stability, and chemical fate and transport.

8.6.1 Summary

Bayou Verdine is divided into five geographic reaches to facilitate data presentation and discussion. The reaches are defined in Section 8.1.2 and Figure 8-1. Bayou Verdine can be characterized as a moderately saline, channelized, moderately low-flow system with significant industrial inflow in the lower three reaches (Reaches 1 through 3). The upper reaches (Reaches 4 and 5) are generally a less-saline, shallow and narrow vegetated low-flow system.

The drainage area for the upper reaches is generally rural to agricultural. The portions of Bayou Verdine from Reaches 1 through 3 receive surface runoff and wastewater discharge from several industrial facilities (Sasol, Conoco, Lyondell, KCSRR and PPG), see Figure 8-2. Contaminants appear to enter the bayou as overland flow or through outfalls. The lower three reaches of Bayou Verdine (Reaches 1, 2, and 3) are subjected to daily tidal fluctuation, tidal storm surge, and seasonal salinity and flow fluctuations.

The greatest extent and concentration of contaminants are seen in Reaches 1 and 2, generally from the Vista West Ditch to below I-10 and from middle Reach 1 to the mouth of Bayou Verdine. The primary contaminant group is HPAHs, however Reach 2 is impacted by dioxin/furans and various VOCs. Concentrations of HPAHs are high as are VOCs, while dioxin/furans are moderately low.

Contaminants of Interest in Bayou Verdine:
PAHs,
Dioxin/Furans,
Metals,
EDC,
and various other
Chlorinated
Hydrocarbons

LPAHs are found near the Conoco Lube Tank Farm in Reach 3. Concentrations are moderately high in this area and exceed levels noted historically. Zinc is the only metal that is consistently elevated above levels noted in the reference area. Zinc is found throughout Reaches 2 and 3 from New Trousdale Road to the Vista West Ditch.

Contaminant occurrence indicates that several sources are present throughout Bayou Verdine. The upstream reaches are relatively un-impacted by industry. The Conoco Lube Tank Farm area appears to be the source of LPAHs and minor HPAHs in Reach 3.

> **Potential Sources to Bayou Verdine – Reach 3**
>
> Conoco Lube Tank Farm

Reach 2 is primarily impacted by releases through the Vista West Ditch and Vinyl Chloride Monomer (VCM) waste water treatment unit discharge, Fabaucher Ditch, releases via Conoco Outfalls 001 and 004, and releases through KCSRR Ditch. Reach 2 is the most heavily impacted segment of Bayou Verdine.

> **Potential Sources to Bayou Verdine – Reach 2:**
>
> Vista West Ditch
> VCM Wastewater Treatment Plant
> Fabaucher Ditch
> Conoco Outfalls 001 and 004
> KCSRR Ditch

Reach 1 appears to be impacted by releases through outfalls that discharged to the upper third of the reach from I-10 through the PPG Derivatives Area (Plant B). Potential sources include the former Conoco, Olin, and Lyondell outfalls that discharge into Bayou Verdine below I-10. Releases to the lower reaches (Reaches 1 and 2) appear to come from PPG outfall 004 and activities (periodic spills and releases) at the North Dock area.

> **Potential Sources to Bayou Verdine – Reach 1**
>
> Olin, Lyondell or Conoco outfalls in upper Reach 1
> PPG Outfall 004
> North Dock Area spill/releases

8.6.2 Conclusions

The primary contaminants of concern to Bayou Verdine are HPAHs, LPAHs, VOCs, dioxin/furans, and zinc, as discussed in Section 8.5.1. Minor PCBs, SVOCs, and pesticides are also present. Contaminants appear to be deposited into the bayou as dissolved constituents, much of which becomes locally adsorbed to sediments or particulate material. Distribution of these contaminants suggests that the sediments or particulates that the chemicals adsorb to may be transported away from the area where the contaminants first entered the bayou.

Concentrations of HPAHs are similar to those observed in previous studies. Vertically, the concentrations of HPAHs tend to be highest in the 15 to 30-cm interval upstream, in Reaches 3 and 4. Meanwhile, HPAHs tend to be highest in the upper (0 to 15-cm) interval in Reaches 1 and 2.

> **Distribution of PAHs in Bayou Verdine (HPAHs and LPAHs)**
>
> - Concentrated occurrence at the Conoco Lube Tank Farm; the area between Vista West Ditch and I-10; and at the mouth of Bayou Verdine
> - Upper Reaches – deeper sediments (15 to 30 cm) are higher in concentration in Reaches 3 and 4.
> - Lower Reaches – surface sediments (0 to 15 cm) are higher in concentration in Reaches 1 and 2.

LPAHs tend to be higher in concentration, however they appear to be occurring in Reach 3 more prevalently than in 1993/1994. It should be noted that the maximum detected value was from BVR2007, upstream of I-10, concentrations in Reach 3 were elevated but not as extreme as this maximum. Vertical distribution is similar to the HPAH distribution.

Historically, dioxin/furans were not analyzed, however dioxin sediment core analyses indicate that only the shallow interval (0 to 15-cm) is impacted, dioxin was not detected at depth.

PCBs were detected in previous studies throughout Reaches 1 and 2, the highest concentrations were noted at the KCSRR Ditch and near the PPG outfall 004 at the mouth of Bayou Verdine. This distribution correlates with current RI findings.

VOCs consisted primarily of EDC and a suite of other chlorinated hydrocarbons including PCE, TCE, 1,2-DCE, chlorobenzene, 4-bromofluorobenzene, dibromofluoromethane and dichloromethane. The greatest concentration of EDC was found near the Vista West Ditch and is well delineated. The EDC appears to be concentrated in a compact area, perhaps present as dense non-aqueous liquid (DNAPL) resting on top of a shallow clay layer. It has been reported that a shallow clay layer dips to the west (dipping upstream from the Vista West Ditch) possibly influencing the upstream extent of the EDC plume. The miscellaneous other VOCs noted extend throughout Reach 2. Concentrations of these other VOCs are moderately high, ranging up to 50,000 μg/kg. RI results are higher, compared to historic concentrations.

EDC

Present in the shallow sediments slightly up and downstream of Vista West Ditch

PAHs, SVOCs, and dioxin/furans are compounds that partition readily to sediments. The attraction to TOC particles or sediment sorption sites is generally strong. There is competition for available sorption sites, and a hierarchy among these chemical groups exists. Typically, compounds with higher partitioning coefficients will accumulate at higher concentration in the sediments or suspended particulate matter. Partitioning coefficients are most important for the following: HPAHs, dioxin/furans, PCBs, pesticides, LPAHs, and SVOCs. Partitioning is less important for most VOCs.

Once adsorbed, the compounds tend to migrate with the matrix material. Reductions in salinity can lead to increased turbulence and suspension of colloidal phase material. This effect can lead to re-suspension of contaminants. Likewise, physical transport of sediment by bed load shear forces appears to be occurring.

Inflow of freshwater into saline water:

- Promotes flocculation of suspended sediments
- Facilitates particle re-suspension

The predominantly silty sand media in Reaches 1 through 3 appears to be subjected to fresh and saline water inflow (some as significant, periodic events) that have been shown to affect sediment bed stability. Organic matter is known to promote flocculation of suspended sediments in estuarine waters (Eisma 1986) and this combined with inflow of freshwater (enough to reduce salinity to below 3 ppt) has been shown to facilitate sediment particle re-suspension. This results in transport of charge-stabilized colloidal suspensions to downstream portions of the bayou or estuary (Johnson and Leenheer 1989). Distribution of contaminants near the larger outfalls indicates that this phenomenon may be having an effect. The surface water salinities noted indicate that the conditions are right and there appears to be localized decreases in many contaminant concentrations at the confluence of these freshwater outfalls or ditches. The sediment concentrations generally increase within 100 to 200 m of the confluence.

Surface water salinity is variable, both spatially and temporally. Salinity observations during the RI ranged from 0 to 21 ppt. In Bayou Verdine, the impact of freshwater inflow from Fabaucher and Vista West Ditch is seen to locally reduce salinity from 15 ppt to 4 ppt. These areas correspond to broad distribution of PAHs, dioxin/furans, indicating that re-suspension and partitioning is occurring throughout this area.

Sediment transport is evidenced by the broad distribution of HPAHs from New Trousdale Road in Reach 3 to the mouth of Bayou Verdine at Coon Island Loop. While multiple sources exist, the broad distribution (observed at BVR3001, BVR3007, BVR2002, BVR2007, BVR1002, BVR1B1CS and BVR1011) along the length of the bayou is indicative of contaminant transport and sediment movement.

The combined processes of adsorption of organic compounds onto suspended particles, salinity-induced flocculation of suspended particles and salting out from the aqueous phase effectively removes many hydrophobic COPCs from the water column. This correlates with the RI data where none of the primary COPCs were noted in surface water.

Primary Transport Processes:

- Salting Out [chemical precipitation]
- Flocculation
- Sediment bed load scouring

Tidal driven flow also appears to strongly affect contaminant distribution. Tidal surge has the combined effect of increased turbulence and shear forces facilitating physical transport and the conveyance of more saline waters into the bayou. Tidal surge associated with coastal storm systems generally create or add to a vertically stratified salinity regime whereby the lower saline body moves upstream while the freshwater layer at the top of the water column moves seaward. These same conditions tend to create strong shear forces along the sediment surface (Grabemann *et al* 1997). The areas most likely affected by tidal surge are Reaches 1 and 2. Reach 1 is closest to the ship channel and its geometry is such that there are no barriers to prevent storm surge in the lower 1,500 m (from Coon Island Loop to I-10). Tidal surge reworking of the sediments is apparent by variable grain size. Sediments in Reaches 1 and 2 are predominantly silty sands.

Multiple sources appear to have contributed to the contamination seen in Bayou Verdine. The data indicates that the release of PAHs, dioxins, and zinc are higher in shallow surface sediments indicating recent deposition versus burial of impacted sediments by clean sediments.

Releases from process areas or outfalls mix with the moderately saline waters of Bayou Verdine, where contamination partitions to the solid or particulate material present. Initial deposition is likely localized, however, tidal surge or freshwater inflow from process waters tends to facilitate sediment transport. The distribution in Reach 2 is an excellent example of how effective freshwater inflow, turbulent flow bed mixing, and particle re-suspension can be in transporting contamination over a relatively large area. The resulting direction of movement is downstream. The addition of tidal surge conditions (increased salinity and re-suspension of sediments) sets the stage for impacted sediment transport to the Calcasieu Ship Channel.